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# LAND-BASED RANGE ESTIMATION

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The present report describes an analysis and evaluation of the range estimation skills involved in the aiming and firing of modern antitank weapons under varying meteorological, illumination, and terrain conditions. Following a detailed presentation of the Ono-Gogel model of distance perception, an attempt is made to explore the model's implications for range estimation. It is concluded that estimating the range of distant targets (beyond 50 meters) requires judgments of both absolute and relative distance of (continued)

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target and non-target objects in the field of view. If weapon users are to attain the level of proficiency needed to guarantee satisfactory hit rates, it is recommended that trainees complete a brief training program in distance estimation. The report also discusses the advantages and disadvantages of several different ranging aids. Finally, several suggestions for additional research are presented.

## FOREWORD

The US Army Research Institute for the Behavioral and Social Sciences has had a continuing program of research responsive to training development for infantry soldier skills. Tracking and engaging moving targets on the battlefield encompasses a wide range of critical, and often difficult, perceptual tasks. Estimating ranges for appropriate target engagement is one such task.

The literature review and theoretical analysis presented in this Research Note provides conceptual guidance for experimental work in the area of perceptual skill enhancement. It presents possible solutions to the problem of training range determination skills.

This research was responsive to Army Project 2Q263743A794, Tracking and Target Engagement for Individual and Crew Served Weapons and will support part of the training program development in this area.

## ACKNOWLEDGEMENT

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BRIEF

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Requirement:

Accurate range estimation in the field has been a problem for the military since the time of Alexander. The problem has been addressed in various forms as part of applied military oriented research as well as in the laboratory. A solution for the military's need to accurately determine range, and particularly the problems facing the infantryman on the battlefield, has not been found. A systematic approach to solving the range estimation problem is necessary and must focus on simple solutions which consider limited training resources.

Procedure and Findings:

A literature search disclosed over 7500 titles relevant to range estimation/determination as well as potential training approaches to enhancing the perceptual skill necessary for the individual soldier to make range related decisions. A model training program and field range is advanced based on a theoretical construct taken from the works of Ono and Gogel. Characteristics of the program and the proposed field range are presented in sufficient detail to allow subsequent development and testing of the training approach.

Utilization of Findings:

Field testing of the Ono-Gogel model remains to be undertaken. The literature review has provided a systematic course through academic and military research in the area of range determination and provides a focus for future research for applied infantry related skill training.

LAND-BASED RANGE ESTIMATION

CONTENTS

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## LAND-BASED RANGE ESTIMATION

## INTRODUCTION

The ability of individual soldiers to aim and fire weapon systems with some degree of accuracy or precision is a major requirement for the success of many types of military operations. Modern weapon systems are vastly more complicated than those in use 25 years ago, but the behavioral demands apparently have changed very little. Furthermore, essentially the same skills seem to be needed with simple weapons such as the rifle as with more complex systems like the LAW, Dragon, and TOW antitank weapons. A detailed analysis is presented in this report, but one of the more critical tasks in the aiming and firing of most weapon systems is the ability to make accurate judgments of target distance, a skill commonly known in the military as "range estimation." If the weapon user has not correctly assessed the distance of the intended target, the quick and accurate detection of enemy personnel and vehicles and mastery of the mechanical demands of a weapon are not very meaningful. A more elaborate statement of the importance of range estimation and its applicability to particular weapon systems in specific military situations is presented in the Human Resources Need (HRN) 78-75 prepared for the Commandant of the U.S. Army Infantry School at Ft. Benning, Georgia.

The present report summarizes an attempt to perform a critical analysis of perceptual cues believed to be important in the judgment of distance under varying meteorological, topographical, and illumination conditions. The report begins with an examination of weapon-related tasks demanded of the combat soldier in field situations, goes on to consider the role and nature of distance judgments in these tasks, reviews and evaluates the current state of knowledge about distance judgment, and concludes with several recommendations about the improvement of range estimation by the individual soldier.

## WEAPON USE AND DISTANCE PERCEPTION

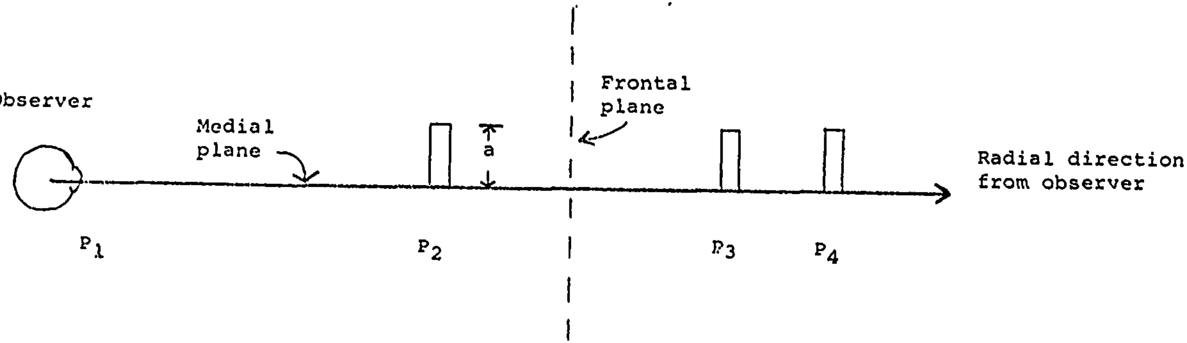
### Weapon Skills

Consider the tasks required of the soldier who has been ordered to seek out certain targets (e.g., enemy personnel or tanks) and to fire a weapon at them. Among the tasks he must perform accurately and quickly are: (a) search out and locate the targets, (b) recognize and identify the target as relevant (e.g., decide that the target _is_ an enemy tank), (c) decide whether the target is within the effective range of the weapon, (d) track the target if it is moving, and compute lead and holdoff, (e) take account of corrections dictated by weapon characteristics (precision of sight alignment, missile velocity) and environmental factors (windage, visibility, terrain, presence of other objects in the firing field), (f) make all the cognitive and motor adjustments required to aim and fire the weapon, (g) perhaps guide or track the missile to the target, and (h) observe whether the target was hit. It seems obvious that the various tasks are closely interrelated and that the adequacy with which one is performed will influence the performance of the others. Nevertheless, it is also clear that accurate range estimation is one of the more critical tasks the soldier must perform. Unless target distance is correctly estimated, good performance of the other tasks is nearly meaningless. Similar, although less crucial, arguments can be made about the importance of the other tasks. Thus, even though theoretical and experimental attention can be focused on any one of the various tasks assumed to be involved in firing a weapon system, it is logically and empirically unsound to ignore the relationships between that task and the other tasks. Finally, it should be kept in mind that the ability to fire a weapon, and to perform the various subtasks, is also a function of the individual soldiers' previous experience with similar situations. Inevitably, with differing backgrounds and training, individual soldiers will achieve different levels of skill in using a particular weapon system.

## Nature of Distance Judgment

With the preceding caveats in mind, consider now the psychological nature of range estimation. Typically, the goal of range estimation is to gauge how far away a particular object is from an observer. While the human observer can use a variety of cues (e.g., visual, auditory, olfactory) to make such judgments, in practice most estimates are based on visual features of the environment because, in man, vision is far superior to the other senses. Furthermore, with some exceptions, vision is the only practical basis of estimation when the object is more than a few meters from the observer. To facilitate consideration of visual range estimation, examine the sketch shown in Figure 1. The figure illustrates in schematic form the basic geometry of distance and size judgment as envisioned by Gogel (1964; 1977), and Ono (1970).

Figure 1 indicates that both size and distance are treated as spatial extent on the frontal and medial planes, respectively. It can be seen that the medial plane extends outward in a radial direction from the observer, parallel to the horizontal dimension. Of course, other medial planes can be defined by specifying other angles to the horizontal. In the case shown in Figure 1, $P_1$, $P_2$, and $P_4$ are arbitrary points located along the medial plane, but defined also by a particular frontal plane, each, in the present example, perpendicular to the medial plane and parrallel to the observer. In considering a series of objects positioned along a medial plane, it is necessary to distinguish among several kinds of distance (Gogel, 1964). Physical distance an (D) is the actual distance of an object ($P_2$, $P_3$, or $P_4$) from an observer ($P_1$). Perceived distance (D') is the apparent distance seen by an observer. It is also labeled the egocentric or absolute distance by Gogel (1977) and Ono (1970) because the observer is one of the reference points. Physical depth (d) is the actual distance between two objects (e.g., $P_2$ and $P_3$) while perceived depth (d') is the apparent distance between the objects as judged by an observer. Since the observer is not one of the reference points, the perceived distance or depth between any two points (e.g., $P_2$ and $P_3$) is also called exocentric, or relative distance (Gogel, 1977; Ono, 1970).




<u>Distance</u> = spatial extent between two points on a single radial direction from observer

1. <u>Egocentric</u> distance = $P_1 - P_2$ , $P_1 - P_3$ , or $P_1 - P_4$

   a. absolute distance
   b. observer is one of reference points

2. <u>Exocentric</u> distance or depth = $P_2 - P_3$ , $P_2 - P_4$ , or $P_3 - P_4$

   a. relative distance
   b. observer is <u>not</u> one of reference points

<u>Size</u> = spatial extent between two points on a frontal plane parallel to observer, but perpendicular to medial plane. Can be described by:

1. <u>Linear unit</u> (extent <u>a</u>) independent of observer location

2. <u>Angular unit</u> (not shown) with observer as apex of the angle

Figure 1. Geometry of distance and size judgment

Just as the spatial extent between points on a medial plane represents what is meant by distance, the spatial extent between points on a frontal plane serves to define the concept of size. There are several kinds of size analogous to distance. Thus, Physical size (S) is the actual size (height and width) of an object. In Figure 1, Extent a designates the height of an object at $P_2$, a linear extent which is independent of the observer. On the other hand, object size can also be specified by the visual angle subtended by an object on the observer's retina. The size of an object on an observer's retina is called retinal size (O), and it is considered proportional to the visual angle of the object. Both linear and angular measures of object size have advantages and disadvantages, depending on the particular application. Perceived size (S') is the apparent size of an object seen by an observer. Familiar or assumed size refers to an observer's memory of object size, and presumably is the result of past experience with an object. Relative size is a cue or source of information which results from the different retinal sizes produced by the simultaneous or successive presentation of two or more similarly shaped objects. Depth will be perceived if the retinal sizes are actually different, with the object with the smaller retinal size appearing farther away. However, Gogel (1964) argues that the perception of depth depends on differences in the perceived size (S') of objects as well as differences in retinal size (O). In particular, he hypothesizes that relative perceived depth (d') is a function of the ratio S'/O, "... the perceived size per unit of retinal size of the particular frontoparallel object being considered" (Gogel, 1964, p. 221). More accurately d' depends on the relative value of two S'/O ratios, one for each object in the visual field.

Thus, Gogel (1964) considers S'/O, the ratio of perceived size to retinal size, the fundamental basis of the relative size cue to depth or relative distance. He also argues that the ratio can be used to describe the perceived depth resulting from the familiar size cue. In both relative size and familiar size, O reflects the retinal size produced by the physical size and distance of the objects in the visual field. In the case of relative size, S' represents the apparent size of the objects as judged by an observer. Under some circumstances, two unfamiliar objects, e.g., two points of light or two identically shaped rectangles, might have the same retinal size, and yet appear at different distances (exhibit depth) because of perceived differences in size. At the other extreme, the objects might have the same apparent size, yet differ in retinal size. Again, the observer would see the objects at different distances. In the case of familiar size, the value of S' will be determined by the observer's memory of object size, and not by the apparent size. If the objects in view are identical in physical shape and size (and thus retinal size), one object may appear more distant if past experience dictates that it is larger than the other object.

Following a review of the experimental evidence, Gogel (1964, p. 223) concludes "... that both perceived size S' and retinal size O are involved in both the relative (retinal) size cue and the familiar (or assumed) size cue to relative depth." He also asserts "... that these two factors are the only factors involved in the size cue to relative depth. When the two factors S' and O are expressed as the ratio S'/O, they can be shown applicable to any objects regardless of the shape or complexity of the objects." The ratio

S'/O is also a variant of the well-known size-distance invariance hypothesis (Epstein, Park, & Casey, 1961). According to Kilpatrick and Ittelson (1953, p. 224), "A retinal projection or visual angle of given size determines a unique ratio of apparent size to apparent distance." In equation form tan A = s/d, where _s_ is the size, _d_ is the distance, and _A_ is the visual angle. Information about any two of the parameters will fix the value of the third. Epstein _et_ al. are very critical of the hypothesis as the primary explanation of space perception, but Gogel (1964) has made good use of the relationship in explicating the role of relative size and familiar size as cues to relative depth, even though he too has reservations about its generality. In his most recent discussion of space perception, Gogel(1977) seems to have relaxed his reservations, and he argues that all the absolute and relative cues to distance can be expressed as ratios, analogous to the S'/O ratio for relative size and familiar size. The components of the other ratios represent, of course, the information provided by the various cues.

Following the earlier suggestions of Gogel (1968), Ono (1970) notes that distance and size judgments can be employed in scalar and nonscalar tasks, with the latter further classified as ordinal or ratio. In a _scalar task_, the response magnitude directly reflects the magnitude of the spatial extent. "Examples of responses that might fulfill scalar tasks would be a ball-throwing response, a reaching response, or making verbal absolute judgment in some metric unit" (Ono, 1970, p. 144). A _nonscalar task_ requires a response based on the relationship between two or more spatial extents. If the response represents relationships such as more than and less than or larger and smaller, the task is classified as ordinal. Ratio nonscalar tasks involve responses which represent a multiple of some extent, e.g., in Figure 1 the distance between $P_2$ and $P_3$ might be judged three times the distance between $P_3$ and $P_4$. More fundamentally, the distinction between scalar and nonscalar tasks is based on whether the observer must make relational or nonrelational responses to spatial extents. Scalar tasks require nonrelational responses while nonscalar tasks call for relational responses. Table 1 combines the distinctions between egocentric and exocentric distances and between scalar and nonscalar tasks and, at the same time, presents an overview of the major cues believed to mediate the various tasks suggested by the orthogonal combination of the task and distance distinctions.

In accordance with the Gogel-Ono classification scheme, judgment of the absolute distance of single objects in the environment is considered a _scalar egocentric task_. The observer is asked to make nonrelational responses to spatial extents in the medial plane, with the observer as one of the reference points. To make the judgments of absolute distance demanded by a scalar egocentric task, Ono (1970) argues that the observer can use the perceptual cues of accommodation and convergence, motion parallax, angle of regard, and familiar size. Accommodation and convergence are muscle processes associated with the focusing of the lens and the turning in and out of the eyes, respectively. The operation of these processes produces distinctive proprioceptive information which presumably permits the observer to make inferences about distance. Motion parallax refers to the different angles (between the eye and objects at different distances) which are generated when the objects or the observer moves. A closely related cue is angle of regard. If an observer can

TABLE 1

Classii .cation of Distance Information According to Task Requirements
(From Ono, 1970)

| | Scalar | Nonscalar: Ratio | Nonscalar: Ordinal |
|---|---|---|---|
| Egocentric | Accommodation<br>Convergence<br>Motion parallax<br>Angle of regard<br>Familiar size | Retinal image size<br>Gradient and perspective | Interposition<br>Retinal disparity |
| Exocentric | | Retinal disparity | Interposition |

An arrow across subsections of the table indicates that the information for one task can also support the other task (s) judge the angle of his line of sight to a point on the ground perpendicular to a distant object and if he knows the height of his eye from the ground (assumed to be horizontal), then, in principle, he can compute the object distance. Ono (1970, p. 145 states that "Familiar size can serve as a source ot information for scalar tasks because familiar objects yield a specific retinal image size at a given distance, and this, in conjunction with the knowledge of the frontal extent of the object, can be utilized as information for the egocentric extent between the observer and the familiar object." Although Ono's statement is somewhat ambiguous, the intent is that given the perceived size S' provided by object familiarity and the linear extent of the object in the frontal plane, the distance is defined solely by geometrical considerations (Euclid's law, or the size-distance relationship; Kaufman, 1974).

It should be clear that the scalar egocentric task, along with the various cues described above, is appropriate for judging the distance of a single object or point in the observer's field of view. When two objects are present (e.g., $P_2$ and $P_3$ in Figure 1), the observer can perform two possible tasks. Figure 1 shows that he can respond to the exocentric distance, $P_2 - P_3$, or the two egocentric distances, $P_1 - P_2$ and $P_1 - P_3$. According to Ono, judgment of $P_2 - P_3$ is a scalar exocentric task involving a nonrelational response which can be performed by use of the cues available in a scalar egocentic task, i.e., if the perceptual information is sufficient for a scalar egocentric task, then it is also sufficient for a scalar exocentric task (note vertical arrow in Table 1). Similarly, Ono argues that the information available in a scalar task is sufficient to support the performance of a nonscalar egocentric task, e.g., ratio of ordinal judgments of the egocentric distances $P_1 - P_2$ and $P_1 - P_3$. Such a task, in the present example, would require comparative or relational responses to the two egocentric extents. Furthermore, if the cues of accommodation and convergence, motion parallax, angle of regard, and familiar size were for some reason not adequate for the performance of a scalar egocentric task, they might nevertheless support a nonscalar egocentric task. Finally, Ono claims that a nonscalar egocentric task can be performed with the cues of interposition, retinal (binocular) disparity, and gradient and perspective, even though these cues will not support a scalar egocentric task. Interposition or the overlapping of objects in the medial plane of the environment, will permit the observer to make ordinal, relational responses, but not ratio responses. Retinal disparity refers to the slightly different retinal images produced in the two eyes by objects in the environment. Ono notes that there is little doubt that this cue is quite effective in nonscalar judgments of exocentric distance, but he argues that it is also sufficient to support ordinal, but not ratio, nonscalar egocentric tasks. Finally, variations in texture density of a surface (and hence perspective) will provide sufficient information to make ratio and ordinal nonscalar judgments of egocentric and exocentric spatial extents.

The preceding discussion of distance perception has considered the various possible tasks an observer might perform in the presence of one and two objects in his field of view. In the case of one object, the observer would perform a scalar egocentric task in which nonrelational responding should produce an estimate of the absolute distance of the object. In the case of two objects, the observer could make a scalar judgment of the distance between the objects or he could make a nonscalar comparison of the two egocentric extents available from the two objects. Still another type of judgment becomes possible when three or more objects are present in the environment. In this case, the observer can make nonscalar judgments (ordinal or ratio) of the exocentric extents between the objects, e.g., $P_2 - P_3$ and $P_3 - P_4$ in Figure 1. Further inspection of Table 1 should clarify the nature of the various tasks.

In a definitive assessment of the theoretical and experimental evidence concerning the perception of distance and various ancillary phenomena, Gogel (1977) agrees with most of Ono's (1970) analysis and classification of distance tasks. However, he argues that is is unrealistic to believe that the judgment of absolute distance is mediated solely by egocentric cues. For one thing, most of the egocentric cues (accommodation and convergence, motion parallax, familiar size) simply don't work with objects more then 2-3m from the observer. Familiar size is perhaps an exception, but Gogel (1977) presents evidence from his own research (Gogel, 1976) and from a study by Eriksson and Zetterberg (1975) which suggests that familiar size is only partially effective as a cue to egocentric distance. Second, the egocentric cues do not, by themselves, yield information precise enough to account for the judgmental accuracy obtained with distant objects. In contrast, according to Gogel (1977), the experimental evidence indicates that exocentric judgments based on retinal disparity, relative size, and relative motion parallax are much more precise, as is the retinal representation of the information provided by these cues. However, it is not possible to simply ignore the egocentric cues to egocentric distance, and thus explain egocentric distance solely in terms of exocentric cues, because (a) some judgmental tasks are devoid of exocentric cues and (b) "... egocentric cues or perceived egocentric distance are necessary to transform (calibrate) the exocentric cues to a perceived scalar distance" (Gogel, 1977, p. 139). Thus, Gogel believes that egocentric perception of distant objects (beyond 3m is based on a combination of the effect of egocentric cues and the summated effect of relative or exocentric cues which have been calibrated or scaled by the various egocentric cues. Finally, the perception of absolute and relative distance is also influenced by two observer tendencies which Gogel explains as the Equidistance Tendency (EDT) and Specific Distance Tendency (SDR). In Gogel's words (1977, p. 134), the EDT " ... states that with the reduction of relative distance cues, objects or parts of objects will tend to appear at the same distance with the effectiveness of this tendency increasing as the directional separations between the objects or parts is decreased (Gogel, 1965). The EDT is a factor in relative (exocentric) distance perceptions and can be in agreement or conflict with relative distance cues. SDT states that with the reduction of cues in egocentric distance, objects will tend to appear at the near distance (about 2m) from the observer (Gogel and Tietz, 1973). The SDT is a factor in egocentric distance perceptions and can be in agreement or in conflict with absolute distance cues". It is important to recognize that these tendencies or response biases become increasingly important with the increasing ambiguity resulting from the gradual reduction or elimination of egocentric and exocentric cues. From a functional point of view, the observer tendencies represent the ability of an observer to make distance judgments even in the presence of considerable stimulus ambiguity (reduced cue conditions). Of course, depending on the particular circumstances facing the observer, the observer tendencies may or may not lead to estimates that are accurate and useful. Nevertheless, it is important to know that distance judgments are influenced by factors other than those of the external environment and the requirements of particular estimation tasks.

As a final point in this examination of distance judgment, it must be kept firmly in mind that the evidence and conclusions provided by Ono and Gogel have been derived from careful, systematic analysis of highly artificial laboratory situations. Neither they nor the present writer claim that the results are applicable to the conditions encountered in the field situations faced by the typical combat soldier. So why devote so much attention to tasks and conditions that are perhaps only marginally relevant to actual field situations? The value of reviewing the theoretical and experimental work of investigators such as Ono and Gogel is at least twofold. On the one hand, the theoretical analyses provide a logical, systematic framework in which to consider all sorts of distance estimation tasks. The theoretical framework may even help point out features of distance judgment in the field which might otherwise be overlooked or ignored. As a case in point, Gogel's (1977) suggestion that egocentric distances serves to calibrate exocentric estimates of distant objects is an idea not considered in traditional discussions of distance perception. On the other hand, the theoretical and experimental research has produced some information that is directly useful. To illustrate, Gogel (1977) and others have amassed considerable evidence that judgments of egocentric or absolute distance cannot be based solely on egocentric cues when the objects are more than a few meters from the observer. In summary, it is anticipated that the preceding examination of the theoretical and experimental nature of distance perception will pay handsome dividends in formulating specific recommendations for the improvement of range estimation by the individual soldier.

## LITERATURE SEARCH

Since both the Contractor and the Principal Investigator possessed very little information about the nature of range estimation, it was agreed that the initial task should be a thorough search of the psychological and military research literature. As noted in the quarterly progress reports, the review encompassed the sources shown below for the indicated periods and/or volumes.

Superintendent of Documents, 1946-1977.

National Technical Information Services. (U.S. Department of Commerce), 1946-1975.

Human Engineering Bibliography (Institute for Applied Psychology, Tufts University), six volumes, 1955-56 - 1960-61.

Psychological Abstracts, volumes for years 1952-1978.

Based on the argument that range estimation cannot be meaningfully divorced from the other tasks involved in the use of a weapon system, a wide range of perceptual phenomena and tasks were included in the literature search. Thus, drawing on all the courses listed above, approximately 7,500 reports were identified as potentially relevant to the project. The reports were subsequently classified into the following major categories.

Range estimation, distance judgment and depth perception.

Illusions related to depth perception and related processes.

Target acquisition, including detection, tracking, search, localization, motion perception, visibility, time perception, night vision, and acuity.

Target identification, including recognition, pattern perception, contour perception, shape constancy, color effects, camouflage, orientation, angle estimation, and slant perception.

Apparatus, including military equipment, visual aids, methodological studies of visual aids, selection and training of operators, marksmanship, terrain evaluation, and navigation.

General, including bibliographies, reviews, books, theories, and miscellaneous topics.

Even though most of the reports were not read, the literature search was valuable in several ways. First, the breadth of the search guaranteed the inclusion of nearly all major studies on range estimation and related phenomena. Second, the breadth also supplied a perspective which is not available in most textbooks and review articles. In one sense, the perspective induced by the search is very similar to the assumption that range estimation cannot and should not be treated separately from other processes and tasks involved in a weapon system. In other words, it is difficult to read and think about a particular problem (e.g., search behavior) without also being forced to consider several other problems. Third, although there was little time to examine the other processes and tasks, the references assembled in the search represent a resource ready for immediate use in future work on similar problems. And finally, the search pointed out the scarcity of investigations concerned with distance judgment under the field conditions and at the ranges important to the combat soldier.

## IMPLICATIONS OF ONO-GOGEL MODEL FOR RANGE ESTIMATION

At the outset, the present project had three major goals: search the military and psychological literature for previous work on range estimation and related phenomena, plan and conduct one or more field studies to test practical procedures of range estimation, and formulate a set of recommendations which could be implemented by company commanders. The results of the first task were both positive and negative. As noted previously very few investigations of distance perception have employed treatment conditions even remotely related to those encountered in the military environment. Although this discovery was partly expected, it was still somewhat disappointing because range estimation is a perennial military problem and therefore one that should have received considerable research attention. Nevertheless, it was found that the literature on space perception is rich in careful experimental studies and stimulating theoretical discussions. At the same time, it became apparent that conducting a few field studies and drawing up a list of recommendations were no longer goals that could be closely related to existing knowledge about range estimation. It was no longer obvious (or potentially obvious) what should be examined in field studies or how they should be conducted. The reason for the uncertainty is that the experimental and theoretical research clearly indicates that distance judgment is vastly more complicated than that suggested by casual observation of weapon firing. And if complexity is a problem in experimental work, then even greater difficulties are likely to be found in field studies. Nevertheless, it is also clear that a series of well-planned field investigations seems urgently needed to examine certain aspects of the experimental and theoretical findings.

However, before attempting to propose field studies or make suggestions for the improvement of range estimation, it will be useful first to consider again the estimation task required of the weapon user, and its relation to the Ono-Gogel classification scheme (Table 1). As noted earlier, if a soldier is to fire a weapon successfully (hit an enemy target), he must decide whether the target is within the effective range of his weapon. In terms of the Ono-Gogel model, if the target is the sole object in the field of view, the soldier must make a scalar judgment of an egocentric distance, using the cues appropriate to that task (Table 1). Disregard for the moment the limited effectiveness of scalar egocentric cues. Once the distance has been gauged in the suggested manner, the estimate is then compared with the maximum effective weapon range. If the estimate is equal to or less than the maximum effective range, a decision to fire the weapon would be appropriate. If the estimate exceeds the effective range, the weapon should not be fired. With just one object before him, the soldier could not make a nonscalar judgment because that task demands relational responses which, in turn, are contingent on two or more objects. For the same reason, he would be prohibited from making scalar or nonscalar judgments of exocentric distances, and furthermore, he needs only know the egocentric or absolute distance of the target in order to decide whether to fire his weapon.

On the other hand, if the field of view does contain objects (trees, rocks, buildings, vehicles, persons) other than the target, then presumably the decision of whether the target is within range of the weapon could be based on cues appropriate to a nonscalar egocentric task. However, in this case, nonscalar judgments of egocentric distances would only tell the soldier that one object was farther away than other objects (ordinal) or that one object was, say, twice as far as another object (ratio). Unfortunately, such judgment by themselves will not produce the distance information needed to make the firing decision.

Still another consideration in determining the absolute distance of a target is the limited range (2-3m) over which the scalar egocentric cues are effective. Given that people can and do estimate the distance of remote objects and given the limited value of scalar egocentric cues, the judgment of distance targets must therefore be based on cues which require relational or nonscalar responses. Retinal disparity is such a cue, but unfortunately, it is also limited to objects close at hand. Another possibility is interposition, but this cue assumes that two or more objects are visually overlapped, a circumstance not always encountered in military settings. However, even if interposition is a viable cue, Table 1 shows that it is useful only in ordinal nonscalar tasks, the least informative type of distance judgments. Thus, the only remaining cues without serious limitations are relative size and relative motion parallax, the two cues Gogel (1977) claims produce the most precise retinal images of spatial extent and motion.[1] Furthermore, as Gogel points out, these cues extend to the limit of the visual field and at the limit, both are different expressions of visual acuity. Visual acuity is the fundamental visual process underlying all spatial discriminations. So it appears that range estimates of most military targets (assumed to be within 50 - 3,500m) must be based, at least in part, on relative size and relative motion parallax because the other distance cues do not provide adequate information. As a final point, it is difficult to think of military situations in which the target is the sole object in the field of view. Except perhaps on a very flat desert, most battlefields have a multiplicity of targets and non-targets.

The emphasis on relative size and relative motion parallax brings the discussion back to Gogel's (1977) suggestion that estimates of distance targets involve a combination of scalar egocentric judgments and the summated effects of relative judgments of exocentric distances which have been calibrated or scaled by the various egocentric cues. At first glance, the suggestion seems unreasonable because it is difficult to imagine an observer summing up a series of egocentric and exocentric distances among a set of objects distributed over his field of view. However, the proposal becomes more plausible if it is assumed that the adult human observer has practiced the summation process countless times during his childhood and youth. Experimental support is apparently still limited (Gogel, 1977), but it is an appealing explanation of how an observer might estimate the distance of targets far beyond the effective range of the usual scalar egocentric cues. As an illustration of how the suggestion might apply in a typical military situation, suppose an enemy tank is spotted on a distant ridge. Between the tank and a soldier with an anti-tank weapon is a cluster of large rocks. Assume also that the distance to the rocks can be evaluated accurately by scalar egocentric judgments, but that the distance between the rocks and the tank requires nonscalar exocentric judgments. If Gogel is correct, the soldier should be able to estimate the total distance (soldier to tank) by combining the scalar and nonscalar judgments of the absolute and relative distances.

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Gogel (1977) dismisses gradient and perspective as basic distance cues because a gradient, and hence perspective, exists for any cue distributed continously in the visual field.

Another consideration in range estimation is the illumination and meteorological conditions of the field of view. If the weather is clear and full sunlight is present, all the cues appropriate to the various tasks should be fully effective (full cues condition). However, with increasing overcast and/or reduced illumination produced by clouds, rain etc., a decrease in cue effectiveness becomes apparent (reduced cues condition). Cue reduction is also guaranteed by the sheer distance of far objects. It has been pointed out before that most distance cues (scalar and nonscalar) are just not effective beyond a few meters. Thus, when targets are at great distances as in many military environments, the observer must depend mainly on the cues of relative size and relative motion, clearly a case of cue reduction. Under these circumstances, sole reliance on relative cues leads to a phenomenon known as underconstancy of distance; perceived distance (D') of an object is systematically less than the physical distance(D). Gogel (1977) claims that some underconstancy occurs with distant objects even with relatively full cues. Thus, whether cue reduction is produced by adverse weather, poor lighting, or the fact that an object is near the limit of the visual field, cue information is highly ambiguous and the various estimation tasks become more difficult to perform. However, underconstancy, the perceived underestimation of physical distance (υ), represents a systematic error and not the random responding (both under-and over-estimation) that would be expected if cue reduction produced genuine perceptual uncertainty or ambiguity. Gogel (1977) suggests that the observer exhibits underconstancy rather than uncertainty because his judgments are being controlled by the two observer tendencies EDT and SDT. He states "With increasing reduction of cues, objects physically separated in depth will tend to be perceived at the same distance according to the EDT and at a distance near to the observer according to the SDT. From either the EDT or SDT, depth segments distant in the visual field would tend to be perceptually underestimated in relation to depth segments nearer the observer" (pp. 171-172). To cap his argument that observer tendencies play an important role in the judgment of distant objects, Gogel (1977) notes that experienced observers (older children and adults) come to realize that they tend to underestimate the distance of far objects, and therefore cognitively attempt to correct their error. Unfortunately, they sometime overcorrect, and produce overconstancy. The overestimation is a deliberate cognitive adjustment made by the observer.

Much of the preceding should be viewed as a speculative attempt to apply the Ono-Gogel analysis of space perception to the range estimation problems of the combat soldier. There is considerable experimental evidence to support most aspects of the analysis (Gogel, 1964, 1968, 1977; Ono, 1970), but it is not known to what extent the experimental findings are applicable to the range problems encountered by the typical weapon user. Furthermore, it would be difficult to design and conduct field studies which would produce unambiguous evidence for the various perceptual mechanisms postulated by Gogel and Ono. Still further, given that weapon users are mainly interested in the destruction of enemy targets, there is little reason for them to be overly concerned with the particular perceptual processes by which this goal is achieved. Nevertheless, the analysis does imply that the use of certain estimation procedures which, if sufficiently well practiced, should improve the estimation skills of most weapon users.

## RECOMMENDATIONS

The present report began with a brief discussion of range estimation and its relationship with other tasks assumed to be involved in aiming and firing a modern weapon system. The report then examined the Ono-Gogel analysis of distance judgment and its implications for range estimation. The questions remaining concern conclusions to be drawn from the analysis and recommendations for the improvement of range estimation.

As a prelude to several recommendations, it will be helpful to first relate the major findings and conclusions of the Ono-Gogel analysis to the estimation problems of the individual weapon user.

1. Distance estimation in laboratory settings is not a simple process, and it is probably even more complex in most military situations.

2. Contrary to the view suggested at the beginning of this report, the weapon user probably cannot estimate target distance by simply judging the absolute (egocentric) distance of the target. The known cues to egocentric distance are just not adequate. Most military targets are far enough away so that the soldier is forced to make judgments about the distances among other objects between him and the target. Thus, the soldier must judge both absolute and relative distances, and combine them, if he hopes to accurately estimate target distance.

3. Any condition which degrades the soldier's ability to see the target clearly (poor weather, reduced illumination, targets near the limit of the visual field) will have a detrimental effect on range estimation. Fortunately, if Gogel is correct about his observer tendencies EDT and SDT, the weapon user will initially underestimate target distance, but, with practice, will learn to overestimate, and hopefully arrive at an accurate estimate.

If the present analysis of distance perception is even approximately correct, it seems obvious that range estimation cannot be instantly and effortlessly improved by offering the weapon user a simple list of tricks or rules of thumb. Instead, the apparent complexity of distance judgment suggests the need of a systematic training program incorporating the use of certain training aids and the development of task-specific performance criteria to be satisfied by each individual trainee. The sequel will describe one possible training program which should produce soldiers whose range estimation skills are commensurate with the demands of current weapon systems. The training program attempts to utilize the findings and conclusions of Ono and Gogel and take advantage of the results obtained by Gibson and Bergman (1954). The latter investigators found that erors in the distance judgments of 18 prepositioned targets on a mown playing field dropped from 33% to 14% in one trial and remained constant over five additional trials. Since no target was repeated in a given series, the improvement or transfer was not specific to particular targets. These results suggest that the skills of range estimation can be learned rather quickly and that the skills are readily transferred to new, unfamiliar objects.

## Training Program

Goals. The first step in any training program is a statement of the goals or objectives to be achieved. Accordingly, in the present case, the goals were expressed in terms of the following questions.

1. What skills need to be learned and to what level of proficiency?

2. Under what environmental conditions should the skills be learned? How much generalizability is needed and/or desired?

3. What characteristics of the learners are relevant to the learning task?

4. What learning aids should be employed in training? What are desirable? What are available?

5. How should the training program be organized or structured? What should be the size cf the learning unit?

Insofar as possible, answers to the questions were included in the training program, and they should be apparent in the subsequent description.

Assumptions. A training program which seeks to achieve a particular set of goals such as those just stated must make certain assumptions about the learners and about the nature of the skills to be mastered. The following list represents the assumptions of the present program.

1. The trainees are male, young (late teens), normal to borderline in intelligence, lower socio-economic status, urban origin, and with limited exposure to and experience with rural environments. Exceptions can always be found, but presumably the descriptions are representative of most trainees.

2. It is assumed that the typical trainee has had little experience with the distance estimation tasks required by current weapon systems, although it would be naive to presume that the trainees have had no experience in the estimation of distance.

3. In accordance with the argument presented earlier in the report, range estimation is viewed as just one of the total set of skills required to fire a weapon system. These skills, in outline form are assumed to be the following.

    a. Systematic observation and analysis of field situations, including noting the presence and locations of target and non-target objects, weather conditions, nature of terrain, presence and location of fortifications, shelters, trenches, etc.

    b. Detection, recognition, and identification of targets and non-targets.

c. Estimation of object distances, and specifically whether a target is within effective weapon range.

d. Aiming and firing a weapon, and observation of results (feedback for corrective actions).

Steps of training program. Although proficiency in weapon firing is the ultimate goal of the present training program, actual firing of a weapon should be preceded by several preparatory phases. Instructional effort devoted to clear explanations and demonstrations of the skills the trainees are expected to master will speed the learning process, help reduce errors, and hopefully minimize the costs involved in the actual firing of weaons. Thus, the training program should consist of the following phases or steps.

1. Classroom lectures covering the following points:

   a. Description and illustration (slides, drawings, etc.) of targets appropriate to the various weapon systems. The instructor should articulate and illustrate the critical, distinguishing features of various targets and non-targets (tanks, trucks, etc.) so each trainee can make the necessary discriminations. Even at the risk of confusion, insofar as possible specific targets should be related to specific weapons so that the trainee can discriminate between appropriate and inappropriate targets re a particular weapon. Consideration should also be given to post-classroom practice on the aforementioned discrimination using training manuals and/or slides, along the lines of the aircraft identification training programs in WWII.

   b. Description and illustration of the terrains likely to be encountered in the field, including appropriate objects such as targets, people, and vegetation. Instruction should also include advantages and disadvantages of various terrains re military operations.

   c. Description and illustration of the value and use of shelters, trenches, etc, in representative field situations. Instructions should focus on their relation to and use of weapon systems.

   d. Description and illustration of various weather and illumination conditions, and their impact on weapon systems. It should be made clear that poor weather and low illumination will produce underestimation in distance judgments and that the weapon user must learn to make a cognitive adjustment for the underestimation.

   e. Emphasis on the need to analyze each field situation in terms of the preceding considerations.

f. Description and illustration of procedures for estimating the distance of target and non-target objects in the battlefield. Instruction should cover the use of ranging aids, optical devices, and weapon sights, and point out sources of error in distance estimation. In addition to the errors produced by adverse weather and poor illumination, the trainees should be informed about the errors associated with objects near the limit of the visual field and the influence of the observer tendencies EDT and SDT on distance estimates.

2. Following or concurrent with the classroom lectures, each individual trainee should become familiar with a number of representative field situations and given the opportunity to see and try out the things he learned in the classroom.

   a. The trainees should be encouraged to examine first hand the target and non-target objects customarily found in field environments, measure the objects with a metric tape measure, and compare the targets with other objects of known size and and shape. The goal is to produce a personal frame of reference for each trainee.

   b. To the extent possible, each trainee should be introduced to various terrains and weather conditions so he can see for himself how they affect his perceptions.

3. Practice in distance estimation should be given in two phases.

   a. In the first phase, the training should be without the use of weapons and in accordance with the procedures described in the next section of the report.

   b. In the second phase, a particular weapon system should be an integral part of the training situation. Although the first phase is designed with the M-16 rifle and the LAW antitank weapon in mind, hopefully the skills learned in the first phase will transfer to the firing of all weapon systems which do not depend on optical magnification.

## Distance Estimation Training

The present section describes a training program designed to improve individual range estimation skills by providing systematic practice and feedback on realistic targets positioned at varying locations on a training range planned especially for estimation training. The range will be referred to as the distance-estimation training range (DETR).

Characteristics of DETR. The general features of DETR are shown in Figure 2. To permit training generalizable to the rifle or the LAW, the total distance of the range (along the line perpendicular to the observer) would be 350m (the drawing only show 250m) and it would be marked off in 25m increments (not visible to the observer). At 25m increments along each arc, postholes would

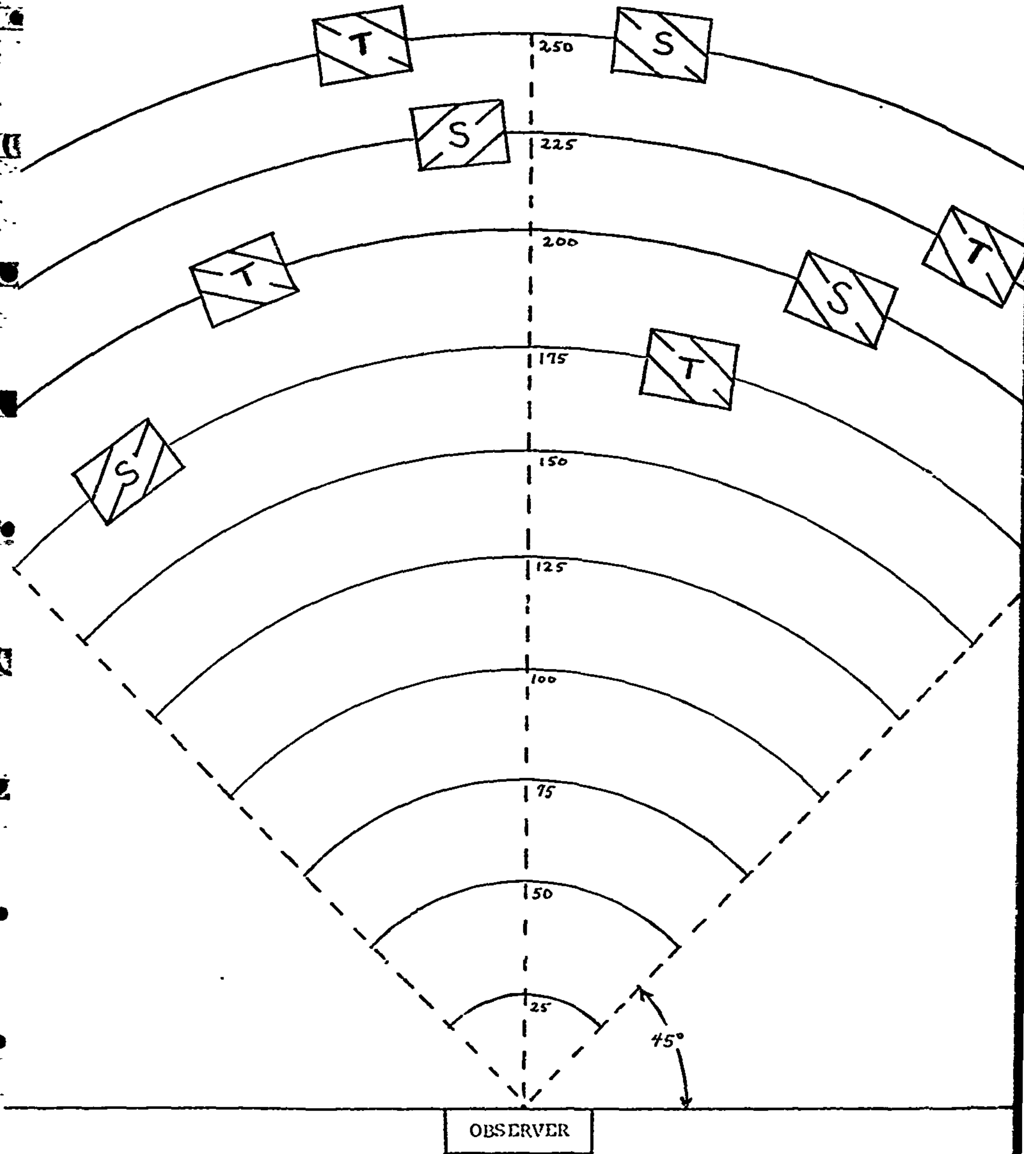


Figure 2. Distance Estimation Training Range

be dug to hold target support poles. As shown in the figure, targets would be restricted to locations 45° on each side of the line perpendicular to the observer. The postholes would permit easy changes in the target locations. The targets would be full-scale replicas of tanks and other appropriate vehicles. The targets could be constructed from plywood or plastic and painted to resemble the target objects. For training purposes, four copies of each target would be needed and each copy should be painted a different color to ensure unambiguous identification of each target. Finally, non-target objects such as trees, rocks, dirt mounds, and small buildings should be mounted on low, flat-bed trailers which could be positioned at various places in DETR.

Use Of DETR. The DETR should be located, if possible, close to the living area of the trainees so it can be used whenever convenient, and not just during formal training periods. In any event, target locations should be changed daily or at least several times each week when the DETR is in use. Target locations should follow a well-planned schedule, making sure that each target is at a different distance and that any given target is not obscured by another target. Figure 2 shows two sets of four targets (labeled S and T) which satisfy these requirements. On a given day, however, only three or four targets should be visible.

During a practice session, the trainee should stand at the point marked Observer and then proceed, with the use of a ranging aid (described below), to decide for each target whether it is within the effective range of a weapon (rifle or LAW). He should then write (or check a block) his Yes or No decision on a prepared answer sheet appropriate to the target display for that session. If possible, the trainee should be told immediately about the correctness of his decisions, but certainly before the next practice session. Immediate feedback is very important for fast and efficient learning. Although the trainees will probably exchange information about the target distances, unless prevented by the instructor, the written responses should minimize compromising, especially if the trainees must satisfy a performance criterion based on their written performance and later performance in the training program. The performance criterion might be 18 correct in 20 successive decisions (90% correct), a widely used criterion in discrimination learning tasks. With the completion of the first training phase contingent on meeting a performance criterion, the number of practice sessions will probably vary with each trainee. During the practice sessions, the instructor should be prepared to review the estimation procedures covered in the classroom, pointing out again the various errors and the use of nontarget objects in judging target distances.

When the criterion has been met for the above task, each trainee should then be asked to make another series of Yes-No decisions with the same targets, but now using the weapon sights (rifle or LAW) to check the correctness of each decision. Again, written responses should be required and each trainee should satisfy the 18/20 performance criterion. As a final test of his ability to judge target distances, each trainee might be asked to make a series of decisions without the use of either a ranging aid or weapon sights. If he meets the 18/20 criterion on this task, he should be ready to test his skills in the actual firing of a weapon. Finally, if possible, some daily sessions should be conducted under different illumination and weather conditions.

It should be recognized that the training program is only a proposal. It has not been tested and obviously should not be put into use until it has been evaluated. Furthermore, many details of the program have been purposely omitted because they require planning decisions and logistic support which can best be handled by instructional personnel assigned to the project. Nevertheless, if the main outline of the program is followed faithfully, the trainees should become competent judges of target distances.

Ranging aids. Many individuals are simply not prepared through past experience to make the distance judgments required by modern weapon systems. For these persons, the use of a ranging aid during the early stages of the training program will probably hasten their acquisition of the estimation skills by giving them confidence in making the judgments and by emphasizing the cues which mediate the judgments. Furthermore, even persons skilled in distance estimation may use a ranging aid to check on a particular estimate when they are uncertain or when they are under considerable stress. These circumstances seem highly likely on an actual battlefield.

Perhaps the simplest ranging aid is based on the two forefingers spread apart in a V-shape and held at arm's length in the medial plane of the line of sight. Consistent use of the fingers, and therefore satisfactory judgment reliability, can be assured at least initially by using a light-weight glove in which finger spread is governed by a thread between the two fingers and by using a neck cord or lanyard attached to the wrist to limit arm extension. Informal observation indicated that a tank-size object approximately 250m in the visual field just filled the space between the first finger joint and the apex of the two fingers. It would be a simple matter to relate (or calibrate) the entire finger length to distance in the visual field. The finger aid is effective because it uses the cue of relative size, one of the cues emphasized by Gogel (1977) in the judgment of distant objects. Perhaps the most important advantages of the finger aid are that it is always available and it is quick and easy to use. No major disadvantages are readily apparent.

The sights of most weapon systems are also effective aids because they also capitalize on the relative size cue. Furthermore, many sights have lines demarking various distances expressed in metric units. In comparison with the finger aid, weapon sights are often complicated and require considerable practice to master their use. In addition, the sights require the user to point the weapon at the object being observed. In some instances, such behavior may be difficult to execute and/or it may disclose the position of the soldier.

Still another possible ranging aid could be constructed from a piece of clear plexiglass and then engraved or labeled with stadia and distance lines. This device is a compromise between the finger aid and a weapon sight although it is simple and portable like one's fingers and its precision is close to that of weapon sights. The major disadvantage is that it can be easily lost unless tied to a cord and attached to the body or clothes.

Finally, range information can be obtained by means of various mechanical and electro-optical devices. Among the simpler mechanical devices are the rangefinders used by golfers and those in 35mm cameras. The main difficulty of these rangefinders is their limited range of operation. An electo-optical device which yields very accurate distance measurements is the laser rangefinder in current use by the U.S. Army, but it is costly, bulky, and constantly requires new batteries. On the other hand, unless distance information can be obtained from battlefield maps or a portable radar system, the laser device may be the best available means of assessing the distance of objects beyond or near the limit of man's visual field. Such is probably the case for the Dragon and TOW weapon systems.

In summary, ranging aids are probably very helpful to the soldier just learning to make distance judgments and even to the more experienced weapon user when he is under stress and thus uncertain about target distance. The finger aid has much to recommend but other devices may be more useful if precise information is needed or if the target is beyond the limits of the unaided eye. In any event, lining up a target in the sights of a weapon and observing whether the target was hit are the ultimate test of all distance estimates.

Additional Research

Although the present project has focused on an examination of distance perception and its implications for a training program to improve the range estimation skills of individual soldiers, there are other aspects of the project which would benefit from further study and analysis. The additional work has been classified somewhat arbitrarily into two categories: empirical and analytical.

Empirical studies. It will be recalled that the training program made certain assumptions about the characteristics of the trainees, the most important perhaps being the relative lack of experience in making distance judgments. On the other hand, objective information about the actual skills of the trainees would permit the development of a training program which could perhaps shorten the time required to meet performance standards. No study was found in the literature survey which investigated the ability to judge distances, although the numerous attempts to construct depth perception tests seem very relevant. Nevertheless, it would be helpful to conduct a modest examination of the distance estimation skills of both trainees and more experienced personnel (qualified weapon users), and then relate the results of the study to those obtained with representative depth perception tests.

Even though the preceding study would likely yield valuable information, a field test of the proposed training program is even more important. Although the proposal seeks to apply the findings and suggestions of previouys investigators, it could probably be greatly improved by careful, systematic tests conducted jointly by ARI and Army personnel. For example, practical considerations might suggest additions and/or deletions in the classroom topics, a different design for the DETR, or more effective learning strategies in acquisition of the estimation skills. To help ensure an objective evaluation of the proposed program, the results should be compared with those of trainees who do not receive the estimation training.

Analytical studies. The present project was restricted by the contract agreement to range estimation problems encountered with antitank weapons, but the resulting analysis and recommendations seem potentially applicable to other weapon systems such as the rifle. The LAW and the rifle are designed for targets, although obviously different in many ways, in approximately the same range. The aiming and firing of both weapons require accurate distance estimates. Probably little effort would be needed to generalize the analysis and recommendations for the LAW weapon to the rifle.

Returning to the oft-made statement that range estimation is just one of several tasks involved in aiming and firing a weapon system, still additional improvements in hit probabilities can likely be achieved by study and evaluation of the other tasks. Just as was true of distance judgment, there is a larger number of experimental and theoretical investigations of search, recognition and identification, and other processes relevant to the behavior of weapon users. Without a doubt, some of this information can be used to improve the weapon skills of both trainees and more experienced soldiers.

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